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TITLE OF THE INVENTION

IMAGE PICKUP APPARATUS, CONTROL METHOD FOR THE SAME,
AND PROGRAM FOR IMPLEMENTING THE CONTROL METHOD

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an image pickup

10 apparatus, a control method for the same, and a program

for implementing the control method, and in particular

to an image pickup apparatus equipped with a function

for manually moving a focusing lens, a control method

for the same, and a program for implementing the

15 control method.

Description of the Related Art

Conventionally, in consumer integrated-lens

cameras, inner focus type lens units that can realize

20 cost reductions, system simplifications, and reductions

in the size and weight of a lens barrel have become

predominant.

FIG. 10 is a schematic diagram showing the

construction of a conventionally used inner focus type

25 lens unit. In FIG. 10, reference numeral 101

designates a fixed first lens group, 102 a second lens

group for zooming, 103 a diaphragm, 104 a fixed third

lens group, 105 a fourth lens group (hereinafter referred to as the "focus lens") that has a focus adjusting function and a so-called compensating function that compensates movement of a focal plane due

5   to the zooming, and 106 an image pickup surface.

In the lens system constructed as shown in FIG. 10, the focus lens 105 has both the focus adjusting function and the compensating function, so that even when the focal distance does not change, the position

10   of the focus lens 105 for focusing on the image pickup surface 106 differs according to the distance to the subject.

If the position of the focus lens 105 for focusing on the image pickup surface 106 is continuously plotted

15   as the subject distance is changed at respective focal distances, focus loci such as those shown in FIG. 11 are obtained. If one of the focus loci shown in FIG. 11 is selected according to the subject distance and the focus lens 105 is moved according to the selected

20   focus locus, zooming can be carried out with no blurring.

To manually move the zoom lens or the focus lens in this kind of inner focus type lens unit, it is customary to provide an operating member that is

25   disposed concentrically with the lens groups and the lens optical axis but is mechanically disconnected from the focus lens 105, to electrically detect an operation

amount of the operating member, and to move the lens by an amount corresponding to the operation amount.

To achieve the same operational feel as a front lens focus type camera or as a professional camera,

5   there has been proposed a method shown in FIGS. 12A to 12D where an encoder formed integrally with a rotating ring engages the lens barrel and the zoom lens or focus lens is moved by electrically detecting the rotational direction and rotational speed of this encoder.

10   In FIG. 12A, reference numeral 600 designates the rotating ring that is disposed in concentricity with the focus lens 104 and engages the lens barrel, with this rotating ring 600 being formed integrally with the encoder 601 with a comb-shaped structure 602. Here,

15   the rotating ring 600 is shown as an operating member for moving the focus lens 105 without actually contacting the focus lens 105, and will be referred to as a "focus ring" hereinafter.

The comb-shaped structure 602 is provided with two

20   light projecting/receiving elements (hereinafter referred to as the "ring rotation sensors") 603, 604 each having a light projecting section 606 and a light receiving section 607 as shown in FIG. 12B. The comb-shaped structure 602 of the encoder 601 passes through

25   gaps between the respective light projecting sections 606 and light receiving sections 607 of the ring rotation sensors 603, 604.

Accordingly, when a tooth of the comb-shaped structure 602 passes through one of the above-mentioned gaps, light from the light projecting section 606 is blocked and is no longer incident on the light

5   receiving section 607, resulting in a large decrease in the output current of the light receiving section 607. Conversely, when a gap between teeth of the comb-shaped structure 602 passes through one of the above-mentioned gaps, light from the light projecting section 606

10   becomes incident on the light receiving section 607, so that there is a large increase in the output current of the light receiving section 607.

When the encoder 601 is rotated, the respective output signals of the ring rotation sensors 603, 604

15   change as shown in FIG. 12C or FIG. 12D. That is, the positional relationship between the ring rotation sensors 603, 604 is determined such that there is a suitable phase difference between the two output signals, and accordingly the rotation amount and/or

20   rotational speed are detected based on the period of changes in the output signals and the rotational direction is detected based on the phase relationship between the two output signals.

It should be noted that the relationship between

25   FIGS. 12C and 12D is such that if FIG. 12C shows output waveforms of the ring rotation sensors 603, 604 when the focus ring 600 is rotated forward, for example, FIG.

12D shows output waveforms of the ring rotation sensors 603, 604 when the focus ring 600 is rotated in reverse.

By providing the encoder 601 shown in FIGS. 12A to 12D and driving a lens actuator such as a stepping motor according to rotating operation of the focus ring 600, it is possible to carry out zooming operations and/or focusing operations using a power zoom and/or power focus while providing the exact same operational feel as a front lens type lens unit even with the inner focus type lens unit (see, for example, Japanese Laid-Open Patent Publication (Kokai) No. H10-10405).

However, during a manual operation of the above-described conventional inner focus type lens unit, if the rotational speed of the focus ring 600 is detected based on the output signals of the ring rotation sensors 603, 604 and control is provided to adjust the focus according to the detected rotational speed, the rotational position of the focus ring 600 at which a focused state is achieved will differ according to whether the focus ring 600 is rotated at low speed or at high speed, resulting in the problem of the focus ring 600 having a different operational feel to a focus ring that is mechanically connected to the focus lens.

On the other hand, if the focus movement amount (focus lens movement amount) is linearly varied in accordance with the rotation amount of the focus ring 600, it is possible to make the rotational position of

the focus ring 600 that results in the focused state

the same regardless of whether the focus ring 600 is

rotated at low speed or at high speed, thereby

realizing the same operational feel as a focus ring

5   that is mechanically connected to the focus lens.

However, when the relationship between the focus

movement amount the rotation amount of the focus ring

600 is made linear as above, it is difficult to obtain

the optimal responsiveness of the focus movement amount

10   to the rotation amount of the focus ring 600.

For example, if the responsiveness is set so low

that focusing can be obtained by slight movements of

the focus ring 600, in operational conditions where

high responsiveness is required, such as the case where

15   rack focus is carried out starting from an extremely

blurred state, the focus ring 600 has to be rotated

many times to rack focus before reaching the focused

position.

On the other hand, if responsiveness is given

20   priority such that a large focus movement amount can be

obtained via a small rotation amount of the focus ring

600, during focusing operations that finely adjust the

focus at close to the focused position, a phenomenon

called "hunting" occurs where a small rotation of the

25   focus ring 600 moves the focus beyond the focused

position and then small reverse rotation of the focus

ring 600 moves the focus back beyond the focused

position once again.

To solve this problem, it is necessary to increase the detection accuracy of the rotation amount of the focus ring 600. To increase the detection accuracy of the rotation amount, it would be possible to make the pitch of the teeth of the comb-shaped structure 602 shown in FIGS. 12A to 12D smaller to increase the number of teeth per rotation, but since there is a limit on the mechanical precision with which such teeth can be formed, it becomes necessary to increase the diameter of the focus ring 600, which hinders reductions being made in size and cost.

Also, in recent years, miniaturization and increased pixel density have been progressing for image pickup elements so that the permissible circle of confusion for picked-up images has become smaller. Therefore, even more precise focus control is now required for the functioning of the encoder 601, and even lower responsiveness of the focus movement amount to rotating operation of the focus ring 600 is desired. If the responsiveness is made lower, however, it is necessary to move the focus ring 600 even further when racking focus from a blurred state, leading to an appreciable decrease in operability.

Further, in the case where photography is continuously carried out with a reduced shutter speed (i.e., so-called "slow shutter photography") so as to

secure sufficient brightness, such as when
photographing a subject in low brightness conditions,
picked-up images are displayed on a monitor or the like
as intermittent images (for example, images displayed

5   in two frames per second when the shutter speed is
1/2sec). Therefore, the photographer can only
intermittently check changes in focus occurring in
response to operations of the focus ring 600 and that
there is a time lag between an operation of the focus

10 ring 600 and the displaying of picked-up images with
the changed focus.

Therefore, even if the ring responsiveness is not
problematic for normal shutter speeds, at slow shutter
speeds, if the photographer tries to change the focus

15 in response to the focusing degree of displayed picked-
up images, the photographer himself/herself will
activate the servo, which results in hunting of the
focus movement and hence in extreme difficulty in
focusing.

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SUMMARY OF THE INVENTION

It is an object of the present invention to
provide an image pickup apparatus and a control method

25 for the same, which are capable of optimizing the
responsiveness of linear changes in focus to operations
of a ring member without sacrificing the operability of

the ring member, while using a small-sized, low-cost
ring member for manual operations, and a program for
implementing the control method.

To attain the above object, in a first aspect of

5   the present invention, there is provided an image
pickup apparatus an image pickup apparatus, comprising
a focus lens, a rotatable ring member, a detection
device that detects a rotating operation state of the
ring member, a control device that causes the focus

10 lens to be moved and stopped in an optical axis
direction thereof based on results of the detection by
the detection device, and a responsiveness control
device that controls responsiveness of linear changes
in focus to the rotating operation state of the ring

15 member detected by the detection device in accordance
with at least depth of focus.

According to the image pickup apparatus of the
first aspect, it is possible to optimize the
responsiveness of linear changes in focus to operations

20 of a ring member without sacrificing the operability of
the ring member, while using a small-sized, low-cost
ring member for manual operations.

Preferably, the image pickup apparatus comprises
an optical lens group including the focus lens, a

25 recording device that records a picked-up image picked
up via the optical lens group onto a recording medium,
and the responsiveness control device controls the

responsiveness of linear changes in focus to the
rotating operation state of the ring member detected by
the detection device in accordance with the depth of
focus that has been corrected based on a pixel density

5   of the picked-up image and a pixel density of a
recorded image to be recorded onto the recording medium.

Preferably, the responsiveness control device
controls the responsiveness of linear changes in focus
to the rotating operation state of the ring member

10 detected by the detection device in accordance with
exposure time.

Preferably, the responsiveness control device
controls responsiveness of a linear focusing movement
amount of the focus lens as the responsiveness of

15 linear changes in focus.

Preferably, the responsiveness control device
controls responsiveness of a linear focusing speed of
the focus lens as the responsiveness of linear changes
in focus.

20 Preferably, the detection device comprises a
photoelectric conversion type sensor.

Preferably, the detection device comprises a
magnetic type sensor.

Preferably, the ring member is disposed in

25 concentricity with an optical axis of the focus lens,
and is mechanically disconnected from the focus lens.

Preferably, the focus lens comprises an inner

focus type lens unit.

To attain the above object, in a second aspect of the present invention, there is provided a control method for an image pickup apparatus including at least

5   a rotatable ring member, a detection device that detects a rotating operation state of the ring member, and a control device that causes a focus lens to be moved and stopped in an optical axis direction thereof based on results of the detection by the detection

10 device, the control method comprising a step of controlling responsiveness of linear changes in focus to the rotating operational state of the ring member detected by the detection device in accordance with at least depth of focus.

15 To attain the above object, in a third aspect of the present invention, there is provided a control program for causing a computer to execute a control method for an image pickup apparatus including at least a rotatable ring member, a detection device that

20 detects a rotating operation state of the ring member, and a control device that causes a focus lens to be moved and stopped in an optical axis direction thereof based on results of the detection by the detection device, the control method comprising a step of

25 controlling responsiveness of linear changes in focus to the rotating operation state of the ring member detected by the detection device in accordance with at

least depth of focus.

The above and other objects, features, and advantages of the invention will become more apparent from the following detailed description taken in

5   conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram showing the
10   construction of an image pickup apparatus according to a first embodiment of the present invention;

FIG. 2A is a diagram showing the electrical connection of a ring rotation detecting circuit shown in FIG. 1;

15   FIG. 2B is a circuit diagram showing an equivalent circuit of the ring rotation detecting circuit;

FIGS. 3A to 3C are diagrams useful in explaining a method of generating an up/down count value by subjecting two-phase pulses to quad-edge evaluation;

20   FIG. 4 is a flowchart showing focusing control based on rotating operation of a focus ring according to the first embodiment;

FIG. 5A is a graph showing changes in F number according to change in depth of focus;

25   FIG. 5B is a graph showing changes in F number according to change in aperture diameter;

FIG. 5C is a graph showing changes in focus

position sensitivity according to change in focal distance;

FIG. 6 is a diagram useful in explaining recording density when still images and moving images are recorded on a recording medium.

FIGS. 7A and 7B are flowchart showing focusing control based on rotating operation of the focus ring according to a second embodiment of the present invention;

FIGS. 8A and 8B are flowchart showing focusing control based on rotating operation of the focus ring according to a third embodiment of the present invention;

FIG. 9A is a graph showing responsiveness of a focus movement amount to a rotation amount of the focus ring in the first embodiment;

FIG. 9B is a graph showing responsiveness of the focus movement amount to the rotation amount of the focus ring in the second embodiment;

FIG. 9C is a graph showing responsiveness of the focus movement amount to the rotation amount of the focus ring in the third embodiment;

FIG. 10 is a schematic diagram showing the construction of a conventional inner focus-type lens system;

FIG. 11 is a graph showing focus loci of a focus/compensating lens during zooming; and

FIGS. 12A to 12D are diagrams useful in explaining an encoder formed integrally with a focus ring.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

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The present invention will now be described in detail with reference to the drawings showing preferred embodiments thereof.

FIG. 1 is a schematic diagram showing the

10   construction of an image pickup apparatus according to a first embodiment of the present invention.

In FIG. 1, light from the subject passes through a fixed first lens group 101, a second lens group (hereinafter, "zoom lens") 102 that carries out zooming,

15   a diaphragm 103, a fixed third lens group 104, and a fourth lens group (hereinafter "focus lens") 105 with a focus adjusting function and a compensating function for compensating for movement of a focal plane due to zooming, so that an image is formed on an image pickup

20   element 106, such as a CCD (Charge Coupled Device).

A focus ring 600, and ring rotation sensors 603, 604 shown in FIG. 1 are the same as described in the related art and have the same functions. A ring rotation detecting circuit 137 is equivalent to a

25   circuit shown in FIG. 2, referred to later.

An optical image that has been formed on the image pickup element 106 by light that has passed through the

respective lenses is subjected to photoelectric
conversion, is amplified to an optimal level by an
amplifier 110, and is then inputted to a camera signal
processing circuit 112 as an image pickup signal

5   (picked-up image signal). The inputted signal is
converted to a normal television signal by the camera
signal processing circuit 112, amplified to an optimal
level by an amplifier 132, and then sent to a magnetic
recording/reproduction apparatus 133 and recorded as a

10   picked-up image. The picked-up image signal is also
sent to an LCD (Liquid Crystal Display) circuit 134 and
displayed on an LCD 135.

It should be noted that information for informing
the photographer of a photographic mode, a photographic

15   state, warnings, and the like are also displayed on the
LCD 135. At this time, a character generator 136 is
controlled by a camera microcomputer 116 to fetch a
character signal relating to the above information, and
the character signal is mixed with the picked-up image

20   signal by the LCD circuit 134 so that the information
is displayed superimposed on the picked-up image on the
LCD 135.

The image pickup signal inputted to the camera
signal processing circuit 112 can also be subjected to

25   a JPEG conversion process using an internal memory and
recorded on a still image recording medium 114 such as
a card medium. In addition, the image pickup signal

inputted to the camera signal processing circuit 112 is

inputted to an AF signal processing circuit 113 that

generates an AF evaluation value. This AF evaluation

value is read by the camera microcomputer 116 and is

5   used for focusing control.

The camera microcomputer 116 detects respective

states of a zoom switch 130 and an AF switch 131, and a

state of a photo switch unit 140. The photo switch

unit 140 has two positions that depend on an amount of

10   depression of the switch. One position is a half

pressing that can result in a focus lock operation

being carried out at the focused position. Another

position is a full pressing (deep pressing) that can

result in an image being captured into an internal

15   memory, not shown, inside the camera signal processing

circuit 112, and a still image being recorded in the

magnetic recording/reproduction apparatus 133, the

still image recording medium 114, or the like.

The camera microcomputer 116 determines whether

20   moving image pickup or still image pickup is being

carried out according to the state of a mode switch

unit 107, and controls the magnetic

recording/reproduction apparatus 133, the still image

recording medium 114, or the like via the camera signal

25   processing circuit 112, to supply a suitable image

signal for the recording medium. When the mode switch

unit 107 is in a reproduction state, the camera

microcomputer 116 provides control such that recorded

images are read from the magnetic

recording/reproduction apparatus 133 or the still image

recording medium 114 and reproduction is carried out

5   based on the read images.

The camera microcomputer 116 has a motor

controller 118, which controls a zoom motor driver 122

and a focus motor driver 126 as described below based

on a computer zoom program 119 to carry out a zooming

10   operation.

That is, when the AF switch 131 is OFF and the

zoom switch 130 is pressed, the motor controller 118

carries out a zooming operation by driving the zoom

lens 102 in one of a telephoto direction and a wide-

15   angle direction depending on a direction in which the

zoom switch 130 is being pressed and also driving the

focus lens 105. At this time, the motor controller 118

sends signals to the zoom motor driver 122 and the

focus motor driver 126 based on lens cam data 120

20   stored in advance to control driving of a lens motor

121 and a focus motor 125.

When the AF switch 131 is ON and the zoom switch

130 is pressed, the focused state needs to be

maintained, so that the motor controller 118 refers not

25   only to the lens cam data 120 but also to an AF

evaluation value signal sent from the AF signal

processing circuit 113 and carries out a zooming

operation while the focus lens is maintained at a
position at which the highest AF evaluation value is
obtained.

   The motor controller 118 carries out focusing
5 control through motor control described below. That is,
when the AF switch 131 is ON but the zoom switch 130 is
not pressed, the motor controller 118 sends, in
accordance with an AF program 117, a signal to the
focus motor driver 126 so that the AF evaluation signal
10 sent from the AF signal processing circuit 113 has the
highest value. By moving the focus lens 105 using the
focus motor 125 in this way, an automatic focus
adjusting operation is carried out.

   When a manual focusing mode is set via the mode
15 switch unit 107 (in the case where the focus ring 600
is rotated in a state where the AF switch 131 is OFF
and the zoom switch 130 is not pressed), the motor
controller 118 provides control to move the focus lens
105 according to the rotating operation state of the
20 focus ring 600 to change the focus according to a
manual focusing operation.

   The camera microcomputer 116 carries out ON/OFF
control of a switch 139 (indicated by symbol Vcc-SW in
FIGS. 2A and 2B) directly connected to a power supply
25 138 to turn on and off the power supply to the ring
rotation detecting circuit 137.

   FIGS. 2A and 2B show the electrical connection of

the ring rotation detecting circuit 137 shown in FIG. 1

and the equivalent circuit of the same, respectively.

It should be noted that the camera microcomputer

116 turns on power to the ring rotation detecting

5   circuit 137 only during the manual focus mode to reduce

power consumption.

When the ring rotation detecting circuit 137 is ON,

photodiodes D (refer to FIG. 2B) of the ring rotation

sensors 603, 604 are lit, but, as the focus ring 600

10   rotates, light is repeatedly allowed to pass and

blocked by the teeth of the encoder 601, so that

respective output signals of phototransistors Tr (refer

to FIG. 2B) are pulse signals (refer to FIGS. 3A and

3B).

15   The two ring rotation sensors 603, 604 are

disposed with a phase difference of 90° between the

respective output signals so that a two-phase pulse

output is sent to the camera microcomputer 116. The

camera microcomputer 116 determines the rotational

20   direction by detecting the phase relationship between

the two-phase pulses, and detects the rotation amount

by counting the number of logical changes in the two-

phase pulses. More specifically, an event counting

function and a pulse accumulator function for two-phase

25   pulses that are provided in microcomputers in general

as normal functions are used to generate an up/down

count value in accordance with the rotational direction

and rotation amount by hardware without skipping pulses.

FIGS. 3A to 3C are diagrams useful in explaining the method of generating the up/down count value by subjecting the two-phase pulses to quad-edge evaluation.

5 FIGS. 3A and 3B show two-phase pulse waveforms obtained with different rotational directions of the focus ring 600, i.e., forward rotation and reverse rotation thereof, and FIG. 3C is a graph schematically showing the generated up/down count value.

10 Here, if the focus ring 600 starts to be rotated in the forward direction as shown in FIG. 3A in the phase state shown by symbol (1) in FIGS. 3A and 3B so that the phase state changes in the order of (1), (2), (3) and (4), the output states of the ring rotation

15 sensors 603, 604 change in the order of (H,L), (H,H), (L,H) and (L,L). As shown in FIG. 3C, such changes in state cause an increase in the up/down count value.

On the other hand, if the focus ring 600 starts to be rotated in the reverse direction as shown in FIG. 3B

20 so that the phase state changes in the order of (1), (2), (3) and (4), the output states of the ring rotation sensors 603, 604 change in the order of (H,H), (H,L), (L,L) and (L,H), so that as shown in FIG. 3C, the up/down count value decreases.

25 The event counter function carries out counting by detecting a detecting edges of the two-phase pulses to detect the status thereof and detecting the high/low

status of one of the two-phase pulses when the other

pulse shows an edge change, to thereby increment or

decrement the up/down count value by 1. This detection

is carried out for both of the two-phase pulses, so

5   that it is possible to generate an up/down count value

in accordance with the rotational direction with quad-

edge evaluation accuracy.

FIG. 4 is a flowchart showing focusing control for

moving the focus lens 105 according to the rotation of

10   the focus ring 600 detected by the detection method

shown in FIGS. 3A to 3C. The focusing control shown in

FIG. 4 is carried out in synchronism with a vertical

synchronization signal for the image signal (this is

also the case with a second embodiment shown in FIGS.

15   7A and 7B and a third embodiment shown in FIGS. 8A and

8B). Also, the focusing control according to the first

embodiment is carried out by the camera microcomputer

116 (this is also the case with focusing control

according to the second embodiment shown in FIGS. 7A

20   and 7B and the third embodiment shown in FIGS. 8A and

8B).

When the process is started in a step S401 in FIG.

4, first the count value that is automatically counted

by the event count function is read (step S402). In a

25   step S403, the read count value is compared with the

preceding count value α and if there is a change in the

count value, it is determined that the focus ring 600

has been rotated so that the process proceeds to a step
S406.

On the other hand, if there has been no change in
the count value, it is determined that the focus ring

5   600 has not been rotated, so that driving of the focus
lens 105 is inhibited (step S404), the count value read
in the step S402 is stored as the preceding count value
α (step S405), and the process is terminated (step
S417).

10   In the step S406, it is determined whether the
count value is higher or lower than the preceding count
value α, and when the count value is higher, the
driving direction of the focus lens 105 is set to a
close-up direction (step S407), and when the count

15   value is lower, the driving direction of the focus lens
105 is set to an infinite direction (step S408).

Next, in steps S409 to S415, the focusing speed is
set in accordance with a difference between the count
value and the preceding count value. A focus driving

20   instruction is outputted to the focus motor driver 126
(step S416), the count value read in the step S402 is
stored as the preceding count value α (the step S405),
and the process is terminated (step S417).

Next, the processing of the steps S409 to S415

25   will be described in detail. In the steps S409 to S413,
pre-processing is carried out to determine the depth of
focus in the present lens state in a step S414. The

depth of focus is expressed as a range (width) of depth

in which no blurring can be visibly recognized, and is

generally expressed as a multiple $F\delta$ of the F number

of the lens and the diameter δ of the permissible

5   circle of confusion.

This value $F\delta$ expresses a range of depth on the

sensitive surface of the image pickup element 106, and

corresponds to a range of relative movement amount in

which changes in focus cannot be perceived even if the

10   focus lens 105 is moved relative to the image pickup

element 106. In the present embodiment where focus is

adjusted by moving the focus lens 105, even if the

focus lens 105 is moved by applying one pulse to the

focus motor 125, the amount of this movement

15   corresponds to an amount of movement of the image

pickup element 106 which is less than the focus

position sensitivity (e.g. 0.8).

Accordingly, in the present embodiment, the depth

of focus when adjusting focus with the focus lens 105

20   is given by Equation 1 below.

depth of focus=$F\delta$/focus position sensitivity.

The F number of the lens includes a so-called

"variable F number" which represents brightness

changing as the amount of light passing through the

25   zoom lens 102 changes with change in the focal distance,

and an F number which is determined by a brightness

adjustment carried out during aperture control, and the

larger one of these F numbers corresponds to the actual brightness of the lens.

Change in the F number with change in the focal distance and change in the F number with change in the

5 aperture diameter are shown in FIGS. 5A and 5B, respectively. FIG. 5C shows the focus position sensitivity of the focus lens 105 that varies with change in the focal distance.

The changes shown in FIGS. 5A to 5C are stored in

10 the camera microcomputer 116 in advance as a look-up table, and a table output value is obtained in accordance with the focal distance ("zoom lens position information", i.e., a number of zoom driving pulses applied to the lens motor 121 in FIG. 1) and the

15 aperture diameter ("aperture position information", i.e., an output from an encoder 129 in FIG. 1) as input variables.

Referring again to FIG. 4, in the step S409 the diameter δ of the permissible circle of confusion is

20 determined by calculation. In general, in the case of a fixed focal distance camera, the diameter δ of the permissible circle of confusion corresponds to approximately double the cell size, that is, the pixel size, of the image pickup element 106. This is because

25 the size of one pixel (cell size) defines the actual resolution limit, but since a low-pass filter is disposed before the image pickup element 106 so as to

prevent alias components of a specific frequency or

above from forming spurious resolution, such as moirés,

on a formed picked-up image, the size of one pixel that

defines the actual resolution limit is equal to the

5   size of approximately two pixels (approximately double

the cell size). This is shown in Equation 2 below.

diameter δ of permissible circle of confusion

= cell size of the image pickup element x 2

Next, based on the position of the zoom lens 102,

10   the F number for the "variable F component" is read

from the look-up table shown in FIG. 5A (step S410),

and the F number corresponding to the aperture position

is read from the look-up table shown in FIG. 5B (step

S411). In the step S412, it is determined that the

15   larger one of the F numbers read in the steps S410 and

S411 is set to the F number for the present optical

system. Also, in the step S413, the focus position

sensitivity corresponding to the present position of

the zoom lens 102 is read from the look-up table shown

20   in FIG. 5C, and in the step S414, the depth of focus is

determined from Equation 1 described above.

The step S415 is for carrying out processing for

setting the responsiveness of the focus movement amount

(change in focus) to rotating operations of the focus

25   ring 600 to a responsiveness standardized according to

the depth of focus, which is a characteristic of the

present invention.

By carrying out the processing in the step S415,
the manner in which the focus changes in response a
rotating operation of the focus ring 600 always depends
on changes in the focus movement amount standardized
5   according to the depth of focus, and therefore the
operational feel experienced by the photographer when
rotating the focus ring 600 to focus the lens is the
same for every kind of photographic scene.

In particular, as the lens F number, which changes
10   in accordance with change in the focal distance and
change in the aperture state, becomes larger, the
responsiveness of the focus movement amount (change in
focus) corresponding to a rotating operation of the
focus ring 600 can be set higher, and therefore it is
15   possible not only to rack focus with a small amount of
rotating operation and but also to carry out fine
focusing near a focused position, while keeping the
apparent change in blurring even.

In the step S415, the focusing speed is changed in
20   accordance with the rotation of the focus ring 600 so
that the focus lens 105 moves with predetermined
characteristics. The focusing speed is expressed as a
number of pulses required for a stepping motor (the
focus motor 125) to move for one second, and is thus
25   expressed in units of pulses/second or "pps". In the
present embodiment, the focus movement amount in one
vertical synchronization period when the focus ring 600

is rotated by a minimum amount is set at 1/4 of the depth of focus. That is, four focus stop positions are present within the depth of focus.

For this reason, the focusing speed Fsp is calculated according to Equation 3 given below. Here, multiplication by the vertical synchronization frequency is carried out to convert the focusing speed Fsp to pps units, and the depth of focus is divided by a movement amount of the focus lens 125 for one pulse to convert the units of distance for the depth of focus to pulse units.

Fsp=1/4 x (depth of focus)/(movement amount per one pulse) x (vertical synchronization frequency) x (rotation amount (|count value-α|))

The response characteristics of the focus movement amount (focusing speed) with respect to the rotation of the focus ring 600 in the first embodiment are shown in FIG. 9A. The focus movement amount changes with linear characteristics with change in the amount of rotation of the focus ring 600. Therefore, the same focus state can be obtained at the same rotational position of the focus ring 600 regardless of whether the focus ring 600 has been rotated slowly or quickly.

As the depth of focus increases, the response characteristics 1101 can be increased as shown by response characteristics 1102. This makes it possible to achieve a fast response for a fast focus rack

without the photographer having to rotate the focus ring 600 many times while maintaining four focus stop positions within the depth of focus even during fine focusing operations.

5   Next, a second embodiment of the present invention will be described.

According to the second embodiment, the responsiveness of the focus movement amount (change in focus) to rotating operation of the focus ring 600 is

10   standardized according to the effective depth of focus based on the ratio of the pixel density of the picked-up image to the pixel density of a corresponding recorded image to be recorded on a recording medium.

       For example, in recording still images onto a card

15   medium or the like, all the pixels of the image pickup element 106 are recorded so that the depth of focus is equal to the diameter of permissible circle of confusion described with respect to the first embodiment. However, in recording moving images, only

20   pixels stipulated by the DV format for a tape medium or the like are recorded, so that the effective depth of focus changes according to the ratio of the pixel density of the picked-up image to the pixel density of a corresponding recorded image to be recorded on the

25   recording medium.

       For example, assuming that the image pickup element 106 has two million pixels, as shown in FIG. 6,

in recording a still image, 1,652 horizontal pixels by 1,244 vertical pixels for the total of two million pixels (see 1201 in FIG. 6) are recorded as they are, so that the diameter of permissible circle of confusion

5   is determined by the cell size of the image pickup element 106. Conversely, in recording a moving image, the number of pixels of the picked-up image is compressed into 1,280 horizontal pixels by 960 vertical pixels for a total of 1.22 million pixels (see 1202 in

10   FIG. 6) and 720 horizontal pixels by 480 vertical pixels for DV format (see 1203 in FIG. 6) are recorded, so that when the photographer views the recorded image, the diameter of permissible circle of confusion has effectively a size produced by multiplying the cell

15   size by 1280/720 in the horizontal direction.

That is, in recording a moving image, the diameter of permissible circle of confusion can be increased 1280/720 times, so that compared to when a still image is recorded, the responsiveness of the focus movement

20   amount (change in focus) to rotational movement of the focus ring 600 can be increased, and conversely, if the responsiveness is not increased by an amount corresponding to the increase in the diameter of permissible circle of confusion, the photographer will

25   not be able to perceive the focus movement on a monitor or the like even if the focus ring 600 is rotated in the opposite direction.

Focusing control in accordance with rotating

operation of the focus ring 600 according to the second

embodiment that takes the above situation into account

will now be described with reference to FIGS. 7A and 7B.

5   It should be noted that the system construction

and the like are the same as those of the first

embodiment, and therefore only parts that differ from

those of the first embodiment will be described here.

Also, steps in the flowchart in FIGS. 7A and 7B that

10   correspond to those in the flowchart in FIG. 4 are

designated by identical step numbers.

Steps S702 to S415 in FIG. 7B are for determining

the responsiveness of the focus movement amount (change

in focus) to rotating operation of the focus ring 600,

15   with processing from the step S702 to the step S414

being for determining the effective depth of focus in

accordance with the ratio of the pixel density of a

picked-up image to the pixel density of a recorded

image to be recorded on a recording medium and

20   processing in the step S415 being for determining the

focusing speed in accordance with the effective depth

of focus in the same way as in the first embodiment.

In the step S702, the diameter of permissible

circle of confusion of the image to be recorded on the

25   actual recording medium is calculated in the

photographic mode. This effective diameter of

permissible circle of confusion is calculated according

to Equation 4 below in which the right term of Equation 2 given above is multiplied by the reduction ratio.

Effective diameter δ of permissible circle of confusion = (cell size of image pickup element x 2) x

5   (cutout pixel density)/(recording pixel density)

Here, "pixel density" corresponds to the number of pixels per angle of view for example, and the cutout pixel density corresponds to the number of pixels cutout angle of view (the diagonal length of the image

10 pickup element 106). When the image pickup element 106 has two million pixels as described above, for example, the pixel density of the image pickup element 106 in the horizontal direction is 1,652 pixels when recording a still image and 1,280 pixels when recording a moving

15 image.

On the other hand, the recording pixel density corresponds to the number of pixels per angle of view on the recorded image and therefore is 1,652 pixels when a still image and 720 pixels when recording a

20 moving image. Thus, when recording a moving image, the diameter of permissible circle of confusion effectively becomes 1280/720 times larger so that the diameter of permissible circle of confusion effectively increases.

In recording a moving image, cutting out of pixels

25 is carried out with a cutout ratio of "1", instead of a cutout ratio less than "1" for reduction, the number of cutout pixels is 720 horizontal pixels by 480 vertical

pixels, so that the effective diameter of permissible circle of confusion is the same as for a still image. Conversely, cutting out of pixels is carried out with a cutout ratio of larger than "1" for enlargement, the

5 diameter of permissible circle of confusion is reduced.

The response characteristics of the focus movement amount with respect to rotation of the focus ring 600 in the second embodiment are shown in FIG. 9B. That is, the larger the reduction ratio of the cutout processing,

10 the deeper the effective depth of focus, which makes it possible to increase the responsiveness.

In this way, according to the second embodiment, the depth of focus that is based on the diameter of permissible circle of confusion determined by the pixel

15 pitch of the image pickup element 106 and the F number of the optical system is converted to an effective depth of focus in terms of the effective diameter of permissible circle of confusion in accordance with the pixel density of the recorded image recorded on a

20 recording medium, whereby the response characteristics of the focus movement amount (change in focus) with respect to rotation of the focus ring 600 can be optimized according to the pixel resolution of the recorded image.

25 For example, during still image photography that records all the effective pixels of the image pickup element 106, the pixel resolution is high, and

therefore, focus rack is carried out in a fine manner with accurate responsiveness according to the pixel pitch of the image pickup element 106. During moving image photography that compresses part of the effective

5   pixels and records the pixels after compression in DV format with 720 horizontal pixels by 480 vertical pixels onto tape, the pixel resolution of the image pickup element 106 apparently becomes lower. Therefore, by rotating the focus ring 600 in accordance with the

10   lower value converted from the pixel pitch, it is possible to increase the responsiveness to focus racks that are often used during moving image photography while keeping the change in blurring in response to rotation of the focus ring 600 even.

15   Next, a third embodiment of the present invention will be described.
In the third embodiment, smooth focusing can be realized by the focus ring 600 even during long exposure conditions, such as at a slow shutter speed.

20   In the third embodiment, description of parts of the system construction and others that are the same as the first and second embodiments is omitted, and only parts that differ from the first and second embodiments will be described.

25   Focusing control according to the third embodiment in response to rotating operation of the focus ring 600 will be described with reference to flowchart in FIGS.

8A and 8B. It should be noted that steps in the flowchart in FIGS. 8A and 8B that are the same as in the flowcharts in FIGS. 4, 7A and 7B are designated by identical step numbers.

5   Steps S702 to S802 in FIG. 8B are for determining the responsiveness of the focus movement amount (change in focus) to a rotating operation of the focus ring 600, with processing from the steps S702 to S414 being for determining the effective depth of focus in accordance

10   with the pixel density of a recorded image to be recorded on a recording medium (this is the same as in the second embodiment) and processing in the step S802 being for determining the focusing speed in accordance with the effective depth of focus and the exposure time.

15   In the step S802, an equation for calculating the focusing speed in the step S802 is used, i.e. Equation 5 given below, which is produced by dividing the right term of Equation 3 described above by a number of exposure fields.

20   Fsp=1/4 x (depth of focus)/(movement amount per one pulse)/(vertical synchronization frequency) x (rotation amount($|$count value$-\alpha|$))/(number of exposure fields)

Here, the "number of exposure fields" is

25   determined by the shutter speed applied during photography. For an NTSC camera, for example, the number of exposure fields is set to "1" for a shutter

speed of 1/60sec or higher, to "2" for a shutter speed

of 1/30sec, and to "30" for a slow shutter speed of

1/2sec.

In this way, as the shutter speed becomes slower,

5   a larger number of exposure fields is set, and as shown

in FIG. 9C, this results in a drop in the

responsiveness characteristics of the focus movement

amount (focusing speed) with respect to rotation of the

focus ring 600. That is, the longer the exposure time,

10   the lower the focus movement amount per unit rotation.

By virtue of this setting, according to the

present embodiment, in the case where photography is

carried out in a photographic mode in which shooting is

carried out at a slow shutter speed so as to achieve

15   sufficient brightness, such as when photographing a

subject in low brightness conditions, it is possible to

solve the conventional problem that picked-up images

are displayed as intermittent images on a monitor or

the like (for example, images are displayed in two

20   frames per second when the shutter speed is 1/2sec) and

the photographer can only intermittently check change

in focus occurring in response to a rotating operation

of the focus ring 600 and hence the photographer

activates the servo by himself/herself to focus in

25   accordance with the display screen, resulting in

repeated hunting of the focus movement, and focusing

can be carried out with ease.

It should be noted that the present invention is not limited to the above first to third embodiments. For example, although in the first to third embodiments, an image pickup apparatus in which a camera and lens

5   are integrated is used, the present invention can be applied to an interchangeable lens type image pickup apparatus that enables interchange of the lens.

Also, although in the first to third embodiments, an optical sensor is used as the rotation sensor that

10   detects the rotation amount, etc. of the focus ring 600 during manual operation thereof, a magnetic sensor may be used. In this case, magnets that have been magnetized with a predetermined magnetizing pitch are disposed around the circumference of the focus ring 600

15   in place of the comb-shaped structure 602 shown in FIG. 6 and FIGS. 12A to 12D, and two-phase magnetoresistive elements (such as MR sensors) are disposed in place of the two photointerruptor elements (ring rotation sensors) 603, 604 disposed in fixed phase relation. In

20   this case, an approximately sine wave-shaped intensity signal and an approximately cosine wave-shaped intensity signal that are output signals of the respective magnetoresistive elements are subjected to waveform shaping into two-phase pulse signals by a

25   signal processing circuit such as a comparator, and the two-phase pulse signals are outputted, so that the rotation of the focus ring can be detected in the same

way.

Compared to the comb-shaped structure 602 required when optical sensors are used, these magnetic sensors can detect the rotational state (rotational direction,

5 rotation amount, rotational speed) of the focus ring 600 with higher accuracy.

As described above, according to the present invention, it is possible to provide an image pickup apparatus that is capable of optimizing the

10 responsiveness of linear changes in focus to operations of the ring member without sacrificing the operability of the ring member, while using, as the ring member, a small-sized, low-cost ring member for manual operations.

It is to be understood that the object of the

15 present invention may also be accomplished by supplying a system or an apparatus with a storage medium (or a recording medium) in which a program code of software, which realizes the functions of any of the above described embodiments is stored, and causing a computer

20 (or CPU or MPU) of the system or apparatus to read out and execute the program code stored in the storage medium.

In this case, the program code itself read from the storage medium realizes the functions of any of the

25 above described embodiments, and hence the program code and a storage medium on which the program code is stored constitute the present invention.

Further, it is to be understood that the functions of any of the above described embodiments may be accomplished not only by executing the program code read out by a computer, but also by causing an OS

5   (operating system) or the like which operates on the computer to perform a part or all of the actual operations based on instructions of the program code.

Further, it is to be understood that the functions of any of the above described embodiments may be

10   accomplished by writing the program code read out from the storage medium into a memory provided in an expansion board inserted into a computer or a memory provided in an expansion unit connected to the computer and then causing a CPU or the like provided in the

15   expansion board or the expansion unit to perform a part or all of the actual operations based on instructions of the program code.

Further, the above program has only to realize the functions of any of the above-mentioned embodiments on

20   a computer, and the form of the program may be an object code, a program executed by an interpreter, or script data supplied to an OS.

Examples of the storage medium for supplying a program corresponding to any of the flowcharts shown in

25   FIGS. 4, 7A, 7B, 8A and 8B described above include a RAM, an NV-RAM, a floppy (registered trademark) disk, an optical disk, a magnetic-optical disk, a CD-ROM, an

MO, a CD-R, a CD-RW, a DVD (a DVD-ROM, a DVD-RAM, a DVD-RW, or a DVD+RW), a magnetic tape, a nonvolatile memory card, and a ROM. Alternatively, the program may be supplied by downloading from another computer, a

5 database, or the like, not shown, connected to the Internet, a commercial network, a local area network, or the like.